Optimized diamond photonic molecule for quantum communications

M. S. Rogachev[1,2], I.Yu. Kateev[1], A.V. Tsukanov[1]

Institute of Physics and Technology, Russian Academy of Sciences[1], Moscow Institute of Physics and Technology, Dolgoprudny[2]

In recent years, elementary quantum optical structures, called photonic molecules (PMs), have been carefully studied both experimentally and theoretically [1, 2]. There structures are formed from high quality factor solid-state microresonators (MR). These devices may be integrated with single-photon sources that generate and guide photon flows in a system and high-sensitivity detectors that fix the arrival of a photon and, preferably, its polarization [3]. As for the element base for quantum computation, the main effort of scientists is now focused on the search for the optimal geometry of a solid-state photonic chip [4]. Here, we propose the design of three-unit PM optimized to obtain good transport and dissipation properties.

To design PM supporting optical-band frequencies, one uses photon cells with geometric dimensions on the order of a few microns. MRs supporting whispering gallery modes (e.g. microrings) can form quasi-one-dimensional optical structures. We optimize diamond microring parameters calculating the eigenfrequencies and the electrical field distributions of the single microring in a broad range of inner and outer radii as well as thicknesses.

Analytical consideration of the PM-system composed of three MRs is given within the formalism of tight-binding phenomenological Hamiltonian:

$$H=\sum_{k=1}^{3}\left(\omega_k-i\kappa_k\right)a_k^+a_k-\sum_{k=1}^{2}J_{k,k+1}\left(a_k^+a_{k+1}+a_{k+1}^+a_k\right), \quad (1)$$

where ω_k is the mode frequency of the k-th MR (k = 1 – 3), a_k^+ and a_k are creation and annihilation operators of photons, respectively, $J_{k,k+1}$ is a coefficient of photon hopping between the MRs, κ_k is a rate of energy dissipation of the MR mode. Provided that $\omega_k \equiv \omega$ and $J_{k,k+1} \equiv J$ each mode of the single MR splits into three ones of PM with frequencies $\omega_{PM1,3}=\omega\pm\sqrt{2}J$, $\omega_{PM2}=\omega$. The electric field profile of PM for the eigenfrequencies $\omega_{PM1,3}$ has antinodes located along the edge of each ring.

The most common mean for controlling the dynamics of photons in PM is laser. Here we employ the weak laser as a probe for the PM's spectrum. The probability of one-photon excitation of PM due to laser photon injection is calculated in the steady-state regime. The transmission spectrum was represented by a small number of clearly distinguishable peaks. As the MRs approach each other, the splitting of the peaks increases. It is very desirable to have *equal* optical field amplitudes in each resonator for some eigenmode of the PM. Our solution consists in following choice of Hamiltonian parameters: $J_{k,k+1} \equiv J$, $\omega_1=\omega_3=\omega$, $\omega_2=\omega+J$. In this case, the mode with the frequency $\omega_{PM,opt}=\omega-J$ is equally-weighted: $\left|\Psi_{opt}\right\rangle=\left(\left|1\right\rangle+\left|2\right\rangle+\left|3\right\rangle\right)/\sqrt{3}$.

References

1. Tsukanov A. V. Quantum dots in photonic molecules and quantum informatics. Part. I // Russian Microelectronics. 2013. Vol. 42. P. 325.
2. Tsukanov A. V. Quantum dots in photonic molecules and quantum informatics. Part. II // Russian Microelectronics. 2014. Vol. 43. P. 165.
3. Yariv A., Xu Y., Lee R. K. and Scherer A. Coupled resonator optical waveguide: a proposal and analysis // Opt. Lett. 1999. Vol. 24. P. 711.
4. Tsukanov A., Kateev I., Orlikovsky A. Quantum register based on structured diamond waveguide with NV centers // Proc. SPIE. 2012. Vol. 8700. P. 87001F.